Towards a Semantic Grid Computing Platform for Disaster Management in Built Environment

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Summary

Current disaster management procedures rely primarily on heuristics which result in their strategies being very cautious and sub-optimum in terms of saving life, minimising damage and returning the building to its normal function. Also effective disaster management demands decentralized, dynamic, flexible, short term and across domain resource sharing, which is not well supported by existing distributing computing infrastructres. The paper proposes a conceptual framework for emergency management in the built environment, using Semantic Grid as an integrating platform for different technologies. The framework supports a distributed network of specialists in built environment, including structural engineers, building technologists, decision analysts etc. It brings together the necessary technology threads, including the Semantic Web (to provide a framework for shared definitions of terms, resources and relationships), Web Services (to provide dynamic discovery and integration) and Grid Computing (for enhanced computational power, high speed access, collaboration and security control) to support rapid formation of virtual teams for disaster management. The proposed framework also make an extensive use of modelling and simulation (both numerical and using visualisations), data mining (to find resources in legacy data sets) and visualisation. It also include a variety of hardware instruments with access to real time data. Furthermore the whole framework is centred on collaborative working by the virtual team. Although focus of this paper is on disaster management, many aspects of the discussed Grid and Visualisation technologies will be useful for any other forms of collaboration. Conclusions are drawn about the possible future impact on the built environment.

1 Introduction

Response to emergencies which pose a risk to infrastructure and human life is an important societal issue. For many types of accidents and natural disasters, the relevant authorities have coordinated action plans that can be deployed. However, recent events have shown that, due to the unpredictable nature of emergencies, the response is often too general and not adapted to the specific emergency. For instance, when a major incident, such as a significant earthquake, occurs, predetermined, static plans are usually brought into operation and any flexibility of response is limited by the ability and competence of those at the scene of the incident to gather relevant data and make appropriate judgments. However, because of the complexity of large buildings, it is impossible for the emergency services to have a full understanding of the situation in terms of the structural integrity and residual strength of a building. The initial response is therefore inevitably cautious and sub-optimal. For instance, dealing with trapped people is a relatively slow process because of safety considerations with regard to the rescuers. Similarly the judgment of what facilities can be returned to normal economic activities and what repairs are needed is a very slow process. Thus there is a need to make the best possible use of advances in information communication technologies to enable a better informed and much faster response to the emergency by using a virtual organisation of experts to provide support for those people at the scene of the emergency.

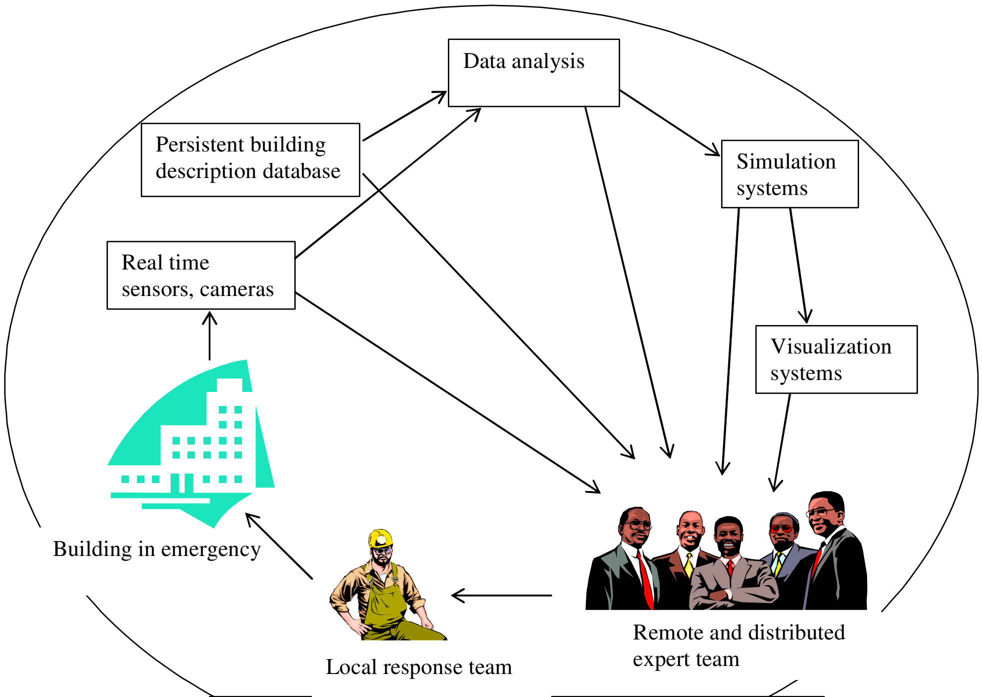

Fig 1. Conceptual communication diagram

This paper proposes a conceptual communication framework (Figure 1) for enhanced communication for disaster management e.g. terrorist attacks, railway collisions, building emergencies, floods etc in the built environment. The framework focuses on the need to rapidly build a virtual organization of experts such as structural engineers who can advise the emergency services on how best to deal with the emergency. Need for exploitation of large scale data sets and CPU intensive applications in the built environment is also addressed. The paper is organised as follows. Initially key enabling technologies for intelligent disaster management, including semantic web, web services and grid computing are discussed. Then need for a Grid Computing infrastructre for disaster management is identified. This is used as a foundation to present an architecture, which brings together key enabling technologies as a framework to support distributed support teams. Key related issues and possible future impact is described in the last section.

2 Enabling Technologies For Semantic Grid Platform

Semantic Grid is an initiative to develop effective methods for enabling semantically enriched complex resource sharing. Semantic Grid adopts a service oriented approach for service delivery, where particular resources are available as services, and consumers negotiates the terms of resource provision. Key enabling technologies of Semantic Grid are summarized in the following section:

2.1 THE SEMANTIC WEB

According to the W3C (2001) the Semantic Web is not a separate Web but an extension of the current one. W3C defines the Semantic Web as a vision: the idea of having data on the Web defined and linked in a way that it can be used by machines not just for display purposes, but for automation, integration and reuse of data across various applications (W3C, 2001). Using the

Semantic Web information is given well-defined meaning, better enabling computers and people to work in cooperation (Berners-Lee et al., 2001). In future, the Semantic Web will provide intelligent access to heterogeneous distributed information, enabling software products to mediate between user needs and information sources available (Fensel and Busler, 2002). Semantic Web technologies offer considerable benefits in terms of project management, content and document management, knowledge management, supply chain management, integration of distributed applications and services and improved efficiency of construction project delivery (Anumba et al., 2003). Semantic Web-based rules, are starting to be applied in large scale distributed systems in the built environment (aecXML, 2003; Cerovsek et al., 2002; e-Construct, 2003; Cheng et al., 2003). However, full realisation of the vision of Semantic Web is possible only when the construction industry agrees on common standards that can be used and extended everywhere.

The relevance of the Semantic Web in the proposed conceptual framework (figure 1) lies in the fact that it will facilitate collaboration between the experts involved in disaster management by supporting information retrieval, information extraction and information processing. Use of Semantic Web technologies will allow the experts involved in disaster management to use highly specific data and services on as-needed basis and in dynamic generation of content.

2.2 GRID COMPUTING

Grid Computing refers to a networked computer model in which processing tasks or applications are split into discrete parts and executed across multiple, independent nodes that are typically distributed over an IP network (Maclver, K., 2003) Grid Computing is distinguished from conventional distributed computing by its focus on large-scale resource sharing, innovative applications, and, in some cases, high-performance orientation. Its main promise lies in the ability to harness the power of large numbers of heterogeneous, distributed resources such as computing resources, data storage systems, instruments etc. (Foster et al., 2001). Thus using a Grid comuting model, an application, database, real time hardware instruments or other network resources etc. can draw on a shared pool of available resources, consuming capacity as needed. The vision is to enable users and applications to seamlessly access these resources to solve complex large-scale problems. There are different architecture for managing a grid of application and services. They range from completely centralized to very distributed.

Main software platform for developing Grid is the Open Source Globus Tool Kit (The Globus Alliance, 2004). Globus toolkit 3 and later versions implements the open grid services architecture (OGSA), which is a set of standards and specifications that integrate Web services with Grid Computing. It also increasingly rely on web-services, for application deployment and delivery mechanism. While the Semantic Web and Web Services offer critical technologies for distributed collaboration, Grids put forward a solution for how to manage the myriad of computing jobs that will arise if such technologies become commonplace (Blythe et al., 2003).

2.3 Web Services

Web services are self-contained, self-describing, modular applications that can be published, located and invoked across the Web. Once a Web service is deployed, other applications (and other web services) can discover and invoke the deployed service regardless of operating system or programming language (Kreger, 2001). The key to Web Services is on-the-fly software creation through the use of loosely coupled, reusable software components (Fensel, D et al., 2002).

Typical Web Services architecture consists of three entities (Figure 2): service providers, service requestors (or clients) and service registries. Service providers publish their services through brokers who maintain registries that clients can look up. The API (Application Programming Interface) for registering services is called Universal Discovery and Description Interface (UDDI). This API enables an enterprise to describe its businesses, its services and how they wish to undertake transactions, search for other businesses that provide desired services and integrate with these businesses to undertake a transaction, if desired. Service requestors (Human users or agents) search services in registries and invoke these services using a Web Interface (WSDL). With the help of information taken from the registries, users invoke the required service, through a Web interface. Simple Object Access Protocol (SOAP) is used to pass object information between applications.

Web services loosely coupled approach suit the construction industry because of temporary, multi-organisation structure of many construction projects, where companies work together for a short period of time. Using Web Services technology, potentially unrelated applications can be linked into composite services, which can than be distributed and accessed through standard internet protocols through wired or wireless devices. In recent years, researchers have demonstrated the applications of web services technology for the construction software application integration (Cheng et al., 2003), construction e-trading services (Cope and Amor., 2002), supply chain integration (Min et al., 2002)and computer aided construction work (Cerovsek et al., 2002).

3 Need For A Grid Based Architecture for Disaster Management

Being able to quickly respond to emergency situations is critical to minimise the impact they can have on human life and the built environment. Ideally such a response requires quick access to and handling of large amounts of dispersed data generated by computationally demanding applications. However managing disasters in built environment is a significant challenge, because many built environment structures are extremely complex artefacts. For instance, a typical large and complex building have associated with it vast amounts of heterogeneous data. The number of components in even a small building is significantly larger than, for example in a car. And much of this data is unique to a particular building. Although there are common features there are also many that are unique. A disaster itself is an event which can contain many unforeseen and unusual features and repercussions. Thus handling an emergency in a large building can rapidly become an extremely complex problem.

Disaster management in built environment primarily requires two types of datasets. The data generated during design and construction and data resulting from real time operations during disaster e.g. video. Data sets generated during the design, construction and operation of buildings is a valuable resource for responding to disasters. However very often data and associated applications may reside at different locations, with the multi-disciplinary teams responsible for the design and construction. Also some applications are specialised , computationally demanding and requires expertise both in its use and the interpretation of the results. In an emergency, it would be useful to be able to reformat and revise this data to provide the emergency services with necessary support e.g. geometric models of the building, virtual representation of the building. In addition, real time data transmission from the disaster site to the virtual teams, would enable the experts to assess the damage and structural integrity of the building and hence advise on residual strength and safety. There are then substantial amounts of data which have to be handled for example large simulation and visualisation programs whose results need to be made widely available. These results need to be annotated with expert interpretation. Also the communication infrastructre need to support the overhead of maintaining communication between the members of the virtual team and a possible requirement for multi-participant virtual meetings.

However the current distributed computing technologies in the built environment are not adequate enough to handle aforementioned requirements of disaster management teams. For instance, current Internet technologies address communication and information exchange among computers but not the co-ordinated use of resources at multiple sites for computation. At the same time, the interoperability of current systems is poor and the access to information and simulation is very limited Also, given the changed circumstances caused by a crisis, it will often be necessary to revise data relating to the building's properties and assess the impact of these using simulations. Current distributed computing approaches do not effectivley address the needs of the disaster management teams to access legacy and real time data software and to make use of high end visualisation to convey their messages and information to the emergency services.

Application of GRID technologies (refer to Section 3.2) have the potential to improve the collaboration between disaster management teams by faciliating the exploitation of large scale data sets and CPU intensive applications and by enabling the rapid formation of virtual teams of engineers and decision makers..

Grid technologies offer the following functionalities making them particularly suited for disaster management applications.

- Interoperability on the protocol level. Technologies based on the Internet, Web, TCP/IP and HTTP address communication and information exchange among computers, but not the coordinated use of resources at multiple sites for computation.
- Scalable design applicable for large resources, flexible sharing relationships, ranging from client server to peer-to-peer and brokered;
- Complex and high levels of control over how shared resources, ranging from client server to peer to peer and brokered;
- Support for sharing of varied resources, ranging from programs, files, and data to computers, sensors and networks; and diverse usage modes, ranging from single user to multi-user. Using Grid infrastructure, heterogeneous systems can be virtualised into a single, unified centrally managed collaborative design environment
- Ability to collect, process and store extremely large amounts of site data.
- Allow rapid dissemination of data between distributed teams, allowing rapid responses to changing project conditions or key events such as disaster management.
- Providing Grid and peer-to-peer approaches to solving complex problems which cannot be solved with current technologies in application fields such as engineering of critical infrastructures and real-time management of large disasters;
- Improving overall modelling, simulation, visualisation and process control as regards risks and emergencies management, therefore increasing speed and flexibility in the related process;
- Participating to some efficient and effective improvement to the overall quality of end products (building, complex civil infrastructures, etc.) as regards security, environmental management, and prevention and detection of risks and disasters.
- The robust nature of Grid with many overlapping routes means that it will still be operational even after a significant disaster;

4 The Architecture

The proposed architecture presented in Figure 3, brings together key technology components i.e. Semantic Web, Grid Services and Visualisation Technologies, as a framework for an intelligent remote collaboration platform for supporting virtual multi-disciplinary teams. Key objectives of the proposed architecture include:

- To provide fast, reliable and secure access to large-scale datasets (some of which require high security protection) and CPU intensive applications in the built environment;
- To provide access to applications for the real-time simulation (rapid execution of virtual experiments) and visualisation of data and physical infrastructures;
- To ensure effective delivery of other applications and services to users on as-needed basis;
- To address the need to respond to events within a limited time frame, and to make decisions with limited information, using distributed personnel;

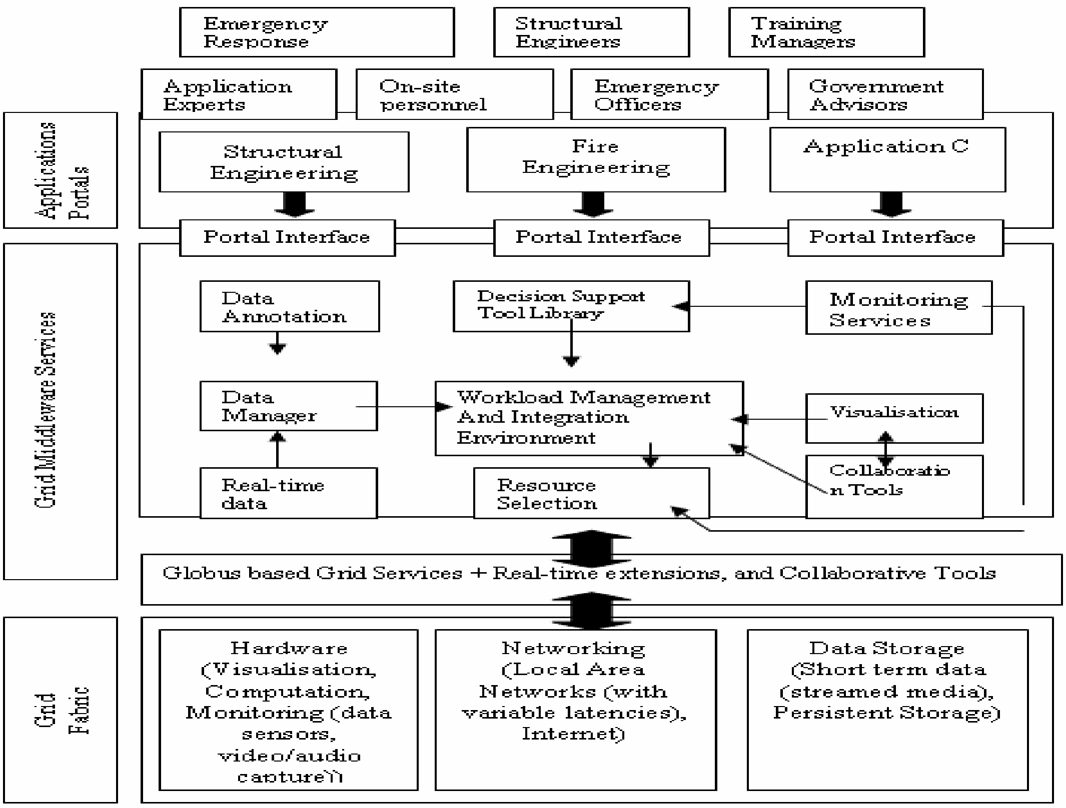

Fig 3: The Proposed Architecture

The architecture is based on multiple layers. The lower layers are composed of a Globus Grid system core services. These include the security service, data migration service, and resource sharing and management services. The subsequent upper layers are built using public domain or commercial software which offer additional services, such as real time information sharing, sharing of the live content and decision support modules to respond to and cope with the emergencies. Each layer publishes an interface which identifies how services within that layer may be utilised and how it may utilise other services in other layers. Key features of the proposed architecture (figure 3) are illustrated in the following section.

4.1 Grid Middleware Services

On top of the Globus layer, Grid services middleware layer provides services such as data management module, decision support module and visualization. These modules support real time content sharing- in particular sharing of data from sensors, and video/audio feeds obtained from the event site. The decision support module work in collaboration with the application portals.

There are three conceptual levels, in the proposed architecture; Data Management Level, information and Knowledge level. They are discussed in detail in ensuing paragraphs;

- Data Level issues handled include security and authorization, resource management, naming services, distributed file systems etc.
- Information level, creation and management of metadata, workflow management, adaptation and personalisation;
- Knowledge management level, automatic annotation and summarisation, dynamic hyper linking and meta-tagging, knowledge representation and visualisation etc.

4.2 Semantic Support

The proposed architecture employs the Semantic Web functionality to allow the disaster management teams to use highly specific data and services on as-needed basis. Semantic annotation using ontologies of all relevant documents, drawings, images, multi-media content etc. would facilitate better indexing and searching. It would also enable improved ways of information retrieval, by describing resources, and links between them. This will facilitate retrieval of critical information at the times of emergency. Such semantic description will also enable those involved in disaster management to intelligently synthesise the content from multiple information sources, on ad hoc and on demand basis. Similar approaches on semantic description of resources exist elsewhere, including :

- ***SCULPTEUR*** (Addis et al.,2003), which aims to create a semantic layer for distributed multi-media information management.
- ***ARTISTE*** (Artiste, 2003), which developed an image retrieval system, based on meta data.
- ***MUMMY*** (Mummy, 2003), which employs ontology-based solutions to enable mobile, personalised knowledge management based on the usage of multimedia.
- ***ANNOTEA (***Koivunen et al., 2003) provide means for users to share communication about Web documents by attaching external annotation metadata to the documents.

The use of meta data and ontology-based description of project resources, services and data enhances and automates processes such as service discovery and negotiation, application composition, information extraction and knowledge discovery and management.

4.3 Visualization Tools

In the proposed architecture, visualisation plays an important role in using the information for decision support to manage the disaster. Grid middleware services will ensure the linkages between the visualization tools and data resources. In the proposed architecture, legacy data resources contain electronic representation of the geometry and contents of the building. It is envisaged that the information will be stored in a number of formats, including CAD files (2 dimensional format) or a more structured information (based on the IFC model for the building information). As these documents e.g. CAD files would have been prepared primarily for guiding the construction of the building rather for their use in disaster management, it is possible that these may be of inappropriate scale and with too much of detail. Thus for optimal utilization of legacy data resources, advanced visualisation tools are employed in the proposed architecture These high level visualisation and image handling tools to assist the remote experts and others with their assessment of risks and handling of the emergency.

In the proposed framework, the basis for the visualization will be the Open-Source Rendering Engine OpenSG (www.opensg.org). This scenegraph allows the management and the real time rendering of different data models like CAD models, annotations, video streams etc. The scenegraph structure can be extended and adapted with the aim to fit the special disaster management requirements and application specific optimisation. Also the information about the building site is designed to appear in graphics layers – each layer offering a finer level of detail about the structure and site. The first layer will comprise the building plan – outlining the location of escape routes, safety locations, corridors etc. The second layer will identify fire or safety equipment available within the building – such as hydrants. The third layer will provide information about structural strength of building (derived from the original plans or stress sensors within a structure). The fourth layer will be the annotations from real-time data obtained from the site. An expert may be able to select which layer to choose at any time, and may selectively choose information from each layer to be displayed on a desktop. This information is shared with other experts using the real-time desktop sharing tools.

4.4 Data Management

The proposed system will handle two types of data: : (1) real-time data generated from video/audio equipment, and data sensors, (2) simulation data obtained from a structural analysis code. Integration environment will ensure locating suitable data from a distributed set of data repositories (including building designs, location of sensors within a building, building owners etc). It will also ensure an integrated access to legacy data repositories.

To facilitate data sharing between the application portals and the integration environment, shared ontologies and web services based interface will be used. Data management aspects in the proposed architecture constitute the following layers:

- Data catalogue: used to identify the location of data sets, and annotations about their quality. Each centre may have its own catalogue, or there may be a catalogue covering a given geographic area. Each catalogue is remotely searchable and accessible via the integration environment.

- File Management system: used to retrieve data from different types of storage devices
- Transfer constraints: identified as annotations on real-time data streams. The transfer constraints will enable reservation of resources (where this is possible).
- Security support: data security and authorization support will be provided to ensure that building designs or schematics can be encrypted where possible.

4.5 Decision Support

The proposed architecture enables the decision making environment, by supporting the remote experts to run simulations by accessing either legacy data sets and software or to provide new simulations. This will help in better assessment of risks and faster response to the emergency. At the time of disaster, there will be significant extra functionality in terms of decision support for assessing risks both in terms of those people who may be in the building, people in the immediate vicinity of the buildings and the emergency services who will be responsible for mitigating the impact of the crisis and saving lives. In addition, if hazardous materials are stored in the building, there may be a further risk to people within a wider area and this risk will also need to be estimated and a strategy for dealing with it devised. Again, the ability of the system to locate and access relevant expertise for any such hazard will be a vital feature. The proposed architecture ensure linkages between the legacy data and software. Also a relationship is maintained between the building data and application of modern, emergency handling procedures. This process will be interesting because the software has been derived for design purposes and much of the data is directed towards anticipating maximum loads and ensuring that the building can withstand these. In an emergency it will be necessary to use actual loads. These cannot be estimated in advance and so novel decision support techniques need to be applied to assess loadings. Also the remote experts will be able to use the proposed framework to estimate what repairs / strengthening work is needed to enable parts of or even the whole building to be returned to its normal use.

4.6 Portal Interface

Portal interface will facilitate relevant human experts in the crisis management tasks, relevant access to legacy data and software applications. At the same time, it will provide real time visulaisation from the disaster site to help the remote experts understand the extent of the emergency and to assess any resulting damage. This will also enable additional simulations to be run and the residual strength and probable performance of the damaged building to be assessed. This information can then be fed back to the emergency services.

4.7 Application Tier:

This tier contains applications. Each application portal will enable the remote experts to annotate building designs and schematics, based on information received from site. This information may include verbal and visual information from on-site personnel, and sensor data obtained from the disaster site. Applications will support the expert to predict likely outcomes, and plan a response.

5 Key Challenges and Outlook

There are quite a few challenges in implementation of the proposed architecture. A key challenge involves the complexity and the immaturity of the Grid software. At present Grid software such as Globus is still relatively unstable and undergoing development. Developing applications, such as proposed in this paper, will form useful testbeds for extending and assessing the current and future capabilities of the Grid in the new areas such as time critical environments with reliability requirements. Another key challenge is to devise a resource model that ensures that the environment works effectively while ensuring that the really critical information is given priority. This will require complex mechanisms and high levels of control to identify and prioritise information and manage the usage of shared resources ranging from program files and data to computers, sensors and real time video while ensuring that the whole network works effectively. Also some of the users will potentially be accessing the software through low band width lines or wireless connections, using the standard web technology. The system has to ensure that they get the right information at right time, on as-needed basis. while allowing others to use the full functionality of the Grid.

Other key technical challenges that need to be addressed include (1) the ability to integrate simulation codes written in various programming languages (C, C++ or Fortran), to support damage assessment, (2) the ability to interact with a number of users using off-the-shelf tools (such as email and the Web), (3) the stringent response time requirements (needed to support real-time video feeds and visualisation), and (4) the large data volumes that may need to be moved or processed – which can best be addressed, collectively, using Grid services and (5) addressing other needs for a flexible but secure virtual organisation.

Improving responses to unexpected events means not only solving technical problems, but also addressing economic, political, social and cultural issues. Response to these unexpected events with risk to infrastructure and human life is becoming an important societal issue. This has been reinforced by recent tragic events that took place in various parts of the world over the last few years. Moreover, in these situations, immediate response should be based on anticipation of the effects of a particular occurrence supported by an adaptable and flexible management team advised by experts who have sufficient knowledge and access to resources to enable them to make high quality judgments with respect to safety and utility.

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